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Algae Removal by the Overland Flow Process

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16. ABSTRACT

Control of algae production will be necessary when lagoons are utilized as a preapplication treatment process for overland flow. The overland flow process has a surface discharge and must meet secondary treatment limitations to be viable. Brief summaries of other algae removal investigations are presented which do not show a relationship between operational and design criteria and discharge concentrations greater or less than the secondary treatment limits for total suspended solids. The data from an investigation conducted at the Robert S. Kerr Environmental Research Laboratory indicate both the number and species of algae in the applied wastewater control the ability of the overland flow process to meet secondary treatment limits for total suspended solids.

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effluent to meet secondary discharge limits, and others[4,5,6] have shown that it will. Brief summaries of these are presented to determine the extent and conditions of the investigations.

The report by Hall *et al.*[2] shows that the overland flow process following a facultative lagoon did not meet the secondary treatment limitations for suspended solids during the summer period at Pauls Valley, Okla. This report evaluated the capability of the overland flow process to treat municipal wastewater with two separate preapplication treatment processes during both summer and winter. There were eight 0.1-ha (0.25 acre) overland flow slopes. The two preapplication treatment processes were screening and a facultative lagoon. The lagoon had four cells, was 13 ha (33 acres) in area, and was designed to treat 13 L/s (0.7 mgd). Lagoon effluent was taken from the second cell after approximately 30 days of detention. The application period and application frequency were 12 h/d and 7 d/wk, respectively. A comparison was made of two application techniques: fixed risers with fan nozzles, or troughs with trickling orifices.

In the winter period, the TSS in the applied lagoon wastewater averaged 26 mg/L, and the discharge from four overland flow slopes averaged between 6 and 20 mg/L. However, in the summer period the TSS in the applied lagoon wastewater was measured 29 times and averaged 114 mg/L. The average concentrations in the discharge from the four slopes over the 6-month summer period were more than twice the secondary treatment limitation (Table 1).

Table 1 describes the operation, design, and average concentrations of influent and effluent of overland slopes receiving lagoon effluent at seven locations.

Hall *et al.*[2] compared the high TSS concentrations in Table 1 with TSS concentrations (which ranged from 1 to 28 mg/L) in the effluents from the four slopes treating screened raw wastewater and concluded that the principal factor affecting treatment was the type of suspended solids, rather than the application method or grade.

Ketchum *et al.*[3] evaluated the overland flow processes at Culver, Ind. The preapplication treatment consisted of a fine screen, a grease trap, and a 1740-m^3 off-line storage lagoon. For 3 weeks in June and July when the average air temperature was 21°C, only wastewater from the storage lagoon was applied to two overland flow plots. This wastewater contained high concentrations of algae that were partially removed by the overland flow processes. For both plots, the application period was 24 h/d and the frequency was 7 d/wk. Average concentrations, design, and operation data are shown in Table 1.

The presence of algae reduced the overall system performance in this midsummer period. The effluent BOD_5 concentrations doubled from that of previous periods, and reached an average of 40 mg/L for one plot and 35 mg/L for the second plot. The effect of the algae was evaluated by comparing soluble and total BOD_5. The differences between the two were 22 and 15 mg/L for the two plots. Algae were cited as the dominating influence in this difference. During this 3-week period, all samples contained greater than 30 mg/L of suspended solids, and one-half were greater than 45 mg/L. The study was terminated before a 30-day average was obtained, but discharges from both plots exceeded 45 mg/L for more than 7 days.

Table 1—Overland flow process and suspended solids.

Location	Wastewater application (cm/d)	Wastewater application ($m^3/m \cdot h$)	Length (m)	Slope (%)	Suspended solids (mg/L) Influent	Suspended solids (mg/L) Effluent
Pauls Valley, Okla.	3.3	0.12	45	2.0	114	61
	3.3	0.12	45	3.0	114	101
	3.3	0.12	45	2.0	114	63
	3.3	0.12	45	3.0	114	66
Culver, Ind.	2.5	0.07	79	4.0	190	47
	5.0	0.14	79	4.0	190	60
Utica, Miss.	2.5	0.05	45	2.0	61	7
	5.0	0.09	45	2.0	58	2
	10.0	0.18	45	2.0	65	10
	20.0	0.37	45	2.0	96	24
Carbondale, Ill.	12.3	0.31	30	7.0	24	10
	12.3	0.31	61	12.0	24	13
Logan, Utah	1.9	0.11	36	2.5	11	15
	3.7	0.22	36	2.5	11	13
	5.6	0.33	36	2.5	11	12
Davis, Calif.	15.0	0.36	46	2.0	121	80
	15.0	0.18	46	2.0	86	24
	15.0	0.18	46	2.0	65	13
Easley, S. C.	2.2	0.16	50	4.0	112	62
	2.9	0.21	50	4.0	112	59
	3.8	0.24	50	4.0	112	51
	2.9	0.20	50	4.0	112	67

Peters *et al.*,[4] in a multifaceted investigation at Utica, Miss., produced data on the reduction of algae and suspended solids by the overland flow process. The treatment system consisted of a lagoon and 24 overland flow slopes. The wastewater applied to the slopes was from a 2.4-ha (6-acre) facultative lagoon. This municipal lagoon was underloaded, and additional inorganic nitrogen and phosphorus were added to make the applied wastewater more representative of secondary municipal effluent.

The study of algae removal by overland flow was conducted during two 4-day periods in the summer. Wastewater applied to the overland flow slopes during the study contained 41 to 61 mg/L BOD_5, 38 to 109 mg/L TSS, 6 to 12 mg/L total Kjeldahl nitrogen (TKN), and 3 to 6 mg/L total phosphorus (T-P). The predom-

inate genera of algae in the applied wastewater were *Oscillatoria* and *Arthrospira*. The application period was 24 h/d. The hydraulic loading rate was changed each day, and replicate loadings were 3 weeks apart. Design, operation, and suspended solids data are shown in Table 1.

Analyses of algae reduction were done by color comparison of filter disks from overland flow runoff. A standard curve was developed from lagoon effluent each day. Average removal was between 75 and 100%. On one occasion the overland flow effluents had TSS values of 40 and 46 mg/L and algae reductions of 60 and 70% from two slopes with a hydraulic loading rate of 20 cm/d. Peters *et al.* stated that, for algae reduction of 90% or greater, wastewater application rates should be less than or equal to 10 cm/d applied continually in a 24-hour period, 7 d/wk. The 1-day duration of the test and the TSS concentration in the applied wastewater were probably insufficient to determine if the overland flow process would remove enough algae from lagoon effluent to meet secondary treatment limits.

Asaturians[5] studied an overland flow system that treated wastewater from a 54-unit mobile home park in Carbondale, Ill., with a population of 135. The system consisted of two parallel septic tanks followed by a single-stage 0.3-ha (0.7-acre) oxidation pond and then an overland flow slope. The overland flow area was not reshaped to a smooth constant grade; the first 30 m had a 7% grade, whereas the lower 31 m had a 12% grade. This terrace was covered by an existing and well-established stand of tall fescue.

The suspended solids removal study was conducted in the spring. The application period was 24 h/d for 21 days. Table 1 presents the results. The low influent concentration indicates that no algal bloom was occurring in the lagoon during this period.

The author observed on several occasions a reduction in green color (algae cells) as water flowed down the slope. He attributed the increase in suspended solids concentration between the 30- and 61-m sampling points to greater water velocities and scouring effects associated with increased slope.

Kemp *et al.*[6] evaluated the effectiveness of overland flow for treating wastewater lagoon effluent on three plots near Logan, Utah. The wastewater was applied 6 h/d, 4 d/wk. Weekly influent and effluent samples were collected for 14 weeks during the summer. Suspended solids concentrations ranged from only 6.4 to 24 mg/L, which suggests that an algal bloom did not occur. Suspended solids concentrations were higher in the effluent from the overland flow process (Table 1). Although these concentrations were near the capability limits of the process, they represented a significant ($P = 0.05$) increase over those in the applied wastewater. The authors concluded a very tight soil texture was needed to prevent excessive scouring of particulate matter (soil erosion) and that Reed Canary, a bunch grass, used alone did not provide a dense enough cover for the filtration of low suspended solids concentrations.

The city of Davis, Calif., added an overland flow process to its existing system. The existing system consisted of comminution, grit removal, primary sedimentation, and three oxidation lagoons operated in parallel, followed by chlorination. The total application area was 69 ha (170 acres). The application period was 4 to 12 h/d, and the design flow was 200 L/s (5 mgd). Smith[7] provided data on operation of the systems during the summer, winter, and fall (Table 1). During the summer the application rate was twice that in the fall and winter.

The overland flow discharge continually exceeded the secondary treatment standard during the 5-week summer period (August 7 to September 1) and for the first 2 weeks of the fall period. Smith[7] attributed the poor summertime performance to excessive application rate, incomplete crop cover, and predominant algal species that were not readily removed by the overland flow process.

Abernathy[8] has evaluated an overland flow process following a facultative lagoon at Easley, S. C. The size of the overland flow plots was based on a design flow of 3.3 L/s (0.075 mgd). The 10 overland flow slopes were operated 5 d/wk with an application period between 5.5 and 8.5 h/d.

During the first 12 months, the average suspended solids concentrations in the applied lagoon effluent and the overland flow effluent were 60 and 40 mg/L, respectively. It was concluded that algal cells produced in the lagoon were the cause of poor TSS removal.

During the second summer of operation, weekly suspended solids measurements were made on the applied lagoon effluent and the effluents from four plots. For a 5-week period, the average concentrations of suspended solids from the four plots were twice the secondary standard of 30 mg/L (Table 1).

A review of these seven previous investigations does not show a consistent relationship between the design and operation and the quality of the effluent relative to secondary treatment requirements. Therefore, satisfactory algae removal by the overland flow process is not a function of hydraulic loading, application rate or length, or terrace slope. The data do support a relationship between influent and effluent concentrations. When the discharge exceeded the secondary treatment limits as a result of algal activity, the influent concentration exceeded 100 mg/L TSS. Algae control seems essential to the use of lagoons as a pretreatment for overland flow.

EXPERIMENTAL DESIGN AND OPERATION

The investigation was conducted at the field site of the Robert S. Kerr Environmental Research Laboratory

in Ada, Okla. This 10-acre site is located adjacent to Ada's wastewater treatment plant. The climate is suitable for year-round operation, and severe weather is not an important concern. Average minimum air temperatures for all months except January are above freezing. The maximum freeze period is 20 days in 22 years of weather data, and the estimated maximum storage requirement is 14 days from the EPA-1 computer program. Average annual precipitation is 100 cm and an average of 26 d/a have more than 1.25 cm. The maximum 24-hour rainfall (25-year return frequency) is 18 cm. The length of the study period was 7 months (May through November 1979). The total rainfall during this period was 70 cm. Rainfall on 9 days was more than 2.5 cm/d and on 17 days more than 1.25 cm/d. The maximum rainfall was 7.2 cm/d. Minimum air temperature dropped slightly below freezing for 2 days, a week before the end of the investigation.

Municipal wastewater was pumped from a large interceptor. Grit was removed from the wastewater by settling. The wastewater was then comminuted and placed in two facultative lagoons. The lagoons were operated in series and had a combined detention time of 30 days. Each circular lagoon had a 6-m diameter and a water depth of 1 m. The sidewall slopes were 3 to 1, and the basins were sealed with a plastic lining. These small lagoons were constructed for a previous investigation, and, because of their size, only 1136 L of wastewater were added each day in five 15-minute increments. This small daily volume of wastewater required modification of an existing overland flow slope. The existing slope measured 11 m wide and 36 m long with a uniform grade of 3%. The terrace was covered with a heavy growth of common bermuda grass. The subsoil was a dense clay with low permeability that restricted downward movement of water. The width of the plot was decreased to 2.13 m by inserting two metal edges along the length of the plot. These metal edges extended from about 5 cm above the grass into the dense clay horizon.

The wastewater was withdrawn at 0.3 m below the surface of the second lagoon and applied to the top of the terrace by a fixed fan nozzle on a riser 0.6 m high. The nozzle orifice was 0.95 cm, and the operating pressure was 1.0 kg/cm^2 (15 psi). The spray pattern was a 145-degree arc with a 1-m radius. The wastewater spray hit a gravel-covered area that was installed to reduce erosion and aid in even distribution. The hydraulic loading rate, application rate, application period, and application frequency were 2.1 cm/d, 0.063 m^3/m · h, 12 h/d, and 6 d/wk, respectively.

Samples of the lagoon effluent and overland flow terrace effluent were collected at weekly intervals. Twenty-five grab samples of each stream were taken during the investigation. Iced samples were transported 4 miles to the laboratory and refrigerated when required. Effluent samples from the toe of the terraces were taken while the runoff was at maximum volume. Previous experience by Law *et al.*[9] showed that the chemical quality of grab samples taken this way was comparable to that of flow-proportional composite samples. Samples were analyzed for 11 chemical parameters. The analytical procedures were selected from those published in "Methods for Chemical Analysis of Water and Wastes."[10]

RESULTS AND DISCUSSION

The 11 chemical parameters measured during this investigation are summarized in Table 2. Influent data in the table describe characteristics of the wastewater after lagoon treatment. The effluent data describe the discharge from the overland flow treatment terrace. The chemical oxygen demand (COD) and total organic carbon (TOC) are rapid measurements that indicate about 50% removal of organic material. Five-day biochemical oxygen demand was not determined, but correlations between BOD_5 and both COD and TOC had been developed during other overland flow investigations at this site.[11,12] From these correlations, the average BOD_5 of the effluent was calculated to be 12 mg/L, and the maximum calculated concentration was less than 30 mg/L. The measured BOD_5 of the raw wastewater was an average of 150 to 160 mg/L in previous investigations,[11] so that the average BOD_5 removal through lagoons and overland flow process was greater than 85%. The discharge met the secondary BOD_5 treatment limits.

Removals of TSS and total volatile suspended solids (TVSS) by the overland flow process were 61 and 55%, respectively (Table 2). Overall removal of TSS concentration in the raw wastewater exceeded 85% over the study period. The average effluent TSS concentration was 26.5 mg/L. The standard deviation was 15.2 mg/L,

Table 2—Summary of concentration data and average removals.[a]

Parameter	Influent		Effluent		Removals (%)
	Mean	Standard deviation	Mean	Standard deviation	
COD	137.6	46.7	69.8	19.0	49
TOC	38.4	16.4	18.5	5.2	52
TSS	63.7	31.2	26.5	15.2	58
TVSS	54.1	27.8	20.8	12.9	61
Total N	8.9	1.9	4.0	1.1	55
NH_3-N	2.6	1.4	0.2	0.1	92
TKN	8.8	1.9	3.3	0.8	62
NO_3-N	0.08	0.06	0.6	0.5	—
Ortho-P	2.1	1.3	2.8	0.7	—
Total P	4.0	4.6	3.3	0.8	17
Cond.	1079.0	201.0	1117.0	198.0	—
pH	8.3	0.5	7.9	1.0	—

[a] In mg/L except for conductance in μmho/cm and pH in standard units.

so that about 16% of the values could be expected to exceed 30 mg/L, and a few might exceed 45 mg/L. In fact, 4 weekly samples did exceed 45 mg/L, and 9 of the 25 measurements exceeded 30 mg/L. However, this did not violate the limitation, which is based on a 30-day average. The 30-day average concentrations are shown in Figure 1. Six of the 21 weekly samples exceeded 30 mg/L, TSS. Five of these were consecutive values and represented a 5-week period. During this period and for 2 weeks prior to this period, the TSS concentration in the applied lagoon effluent increased 50% from an average of 54 mg/L to an average of 82 mg/L. Both the lagoon effluent and overland flow effluent during this period had a green color because of the presence of algae. Microscopic examinations of these effluents showed large numbers of several algal species. The overland flow process failed to remove sufficient algae from the lagoon effluent to meet the 7- and 30-day average TSS concentrations in the secondary treatment limits.

The overland flow process reduced the total nitrogen concentration by 55% over the study period. The removal of total Kjeldahl nitrogen (TKN) from the wastewater was 62%. The ratio of total nitrogen to TKN in both the influent and effluent was practically constant throughout the study period. Both physical and biological mechanisms were considered responsible for nitrogen removal.

The other forms of nitrogen in Table 2 are ammonia nitrogen (NH_3-N) and nitrate nitrogen (NO_3-N). The more significant changes in concentration of these forms of nitrogen show a relationship with temperature that was consistent with biological activity (Figure 2). The highest concentration of NH_3-N in the lagoon effluent was 5.8 mg/L and occurred in August, the month that had the highest air temperatures. These NH_3-N concentrations generally increased and decreased with temperature. The concentrations of NH_3-N from the overland flow slope were consistently low with a maximum value

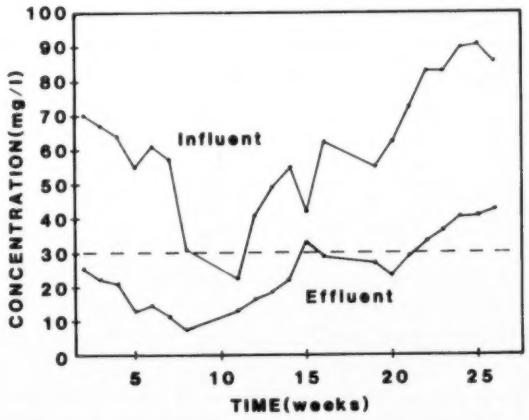

Figure 1—Suspended solids—30-day moving average.

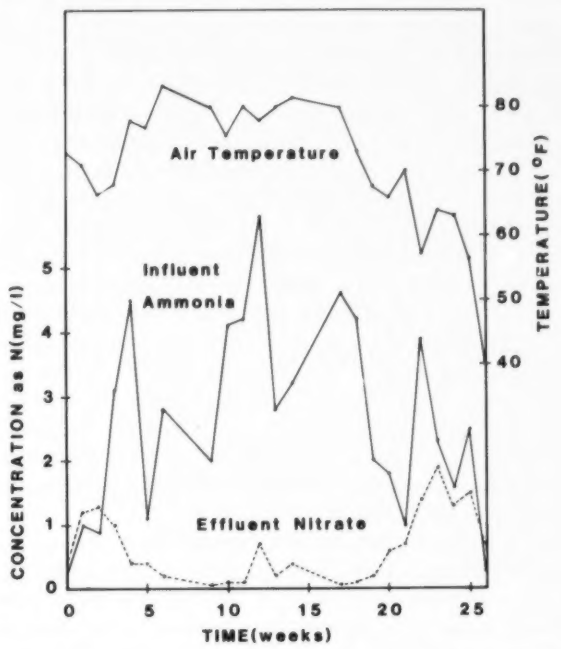

Figure 2—Comparison of nitrate, ammonia, and temperature.

of 0.5 mg/L. The NO_3-N concentrations in the overland flow effluent had an opposite relationship. The higher values occurred during May and October, months that had lower air temperatures (Figure 2). The influent values were consistently low, with a maximum value of 0.3 mg/L. Both nitrification and denitrification are known to increase with temperature. This nitrate curve indicates that the decrease in denitrification with temperature was more rapid than the nitrification and resulted in higher NO_3-N concentration in the discharge during periods of lower temperatures. Denitrification also requires anaerobic conditions. Oxygen concentrations in the wastewater are higher at lower temperatures and may have reduced the anaerobic zone on the slope.

The average removal of total phosphate (Total-P) was 17%. Concentrations of the orthophosphate portion (Ortho-P) increased over the overland flow slope. The slope used for this investigation had treated raw and secondary wastewaters for the previous 10 years, and the remaining phosphate exchange capacity of the soil was apparently low. Conductivity (Cond.) measurements show a small increase in the salt concentrations, thereby confirming that water evaporation took place on the slopes. The change in pH was minor and remained in a suitable range for biological activity.

The failure of the overland flow process to meet secondary treatment standards is attributed to the algae in the effluent from lagoons used for preapplication treatment. The type of algae may be a controlling factor in the capability of the overland flow process to meet secondary standards. To evaluate algae removal, three sam-

Table 3—Plankton count, Ada, Okla.

Organisms	Size (μ)	Lagoon effluent			Overland flow effluent		
		Aug. 1	Oct. 18	Nov. 1	Aug. 1	Oct. 18	Nov. 1
Chlorophyceae—green							
Ankistrodesmus sp.	60-90	—	1 250	1 090	—	160	430
Chlamydomonas sp.	20-30	1 470	300 600	149 900	—	135 320	30 160
Chlorella sp.	10	—	52 500	112 000	—	1 360	45 000
Scenedesmus sp.	18-34	4 460	1 570	380	136	380	160
Volvox sp.	300-500	—	22 000	160	204	1 570	110
Pandorina sp.	20-40	1 030	—	—	95	—	—
Protococcus sp.	20	—	—	82 400	—	—	220
Chrysophyceae—yellow-brown							
Mallomonas sp.	40-85	—	1 300	3 690	42	320	1 190
Synura sp.	100-400	540	—	—	—	—	—
Bacillariophyceae—diatoms							
Anomoeoneis sp.	60-100	—	97 400	52 400	—	67 400	270
Navicula sp.	12-17	—	—	—	109	380	—
Total number/mL		7 500	477 120	402 020	586	206 890	77 540
TSS (mg/L)		45	87	72	21	39	36

ples of the lagoon effluent and overland flow effluent were taken when suspended solids concentrations were known. The species of algae and diatoms were identified and counted. The results are shown in Table 3.

The total numbers of plankton/mL increased with the concentration of suspended solids. The overland flow process reduced the number of all species of algae and diatoms in the lagoon effluent. The total number of plankton was two to three orders of magnitude fewer in both the lagoon effluent and the overland flow effluent in August, when the effluent complied with the secondary standard, than in October and November when it did not.

The plankton that increased most significantly in the lagoon and overland flow effluents were the green algae *Chlamydomonas* and *Chlorella* and the diatom *Anomoeoneis*. These free-floating species were smaller and less likely to aggregate than the other species identified. Large numbers of the green algae *Protococcus* in the applied lagoon effluent were absent in the overland flow effluent. This species is characterized by copious mucilaginous material around their bodies, and often aggregate. It is assumed that these algae were removed by entrapment in the vegetation and soil.

These data show that both the number and species of plankton in the applied wastewater control the ability of the overland flow process to meet secondary treatment limits.

CONCLUSIONS

The use of facultative lagoons for preapplication treatment for the overland flow process has economic advantages where storage is needed or where more than screens or comminutors are required.

The overland flow process has a surface discharge and must meet NPDES secondary treatment limitations to be viable.

Some previous investigations have demonstrated that the discharge from the overland flow process following a facultative lagoon will meet secondary treatment limits, and others have concluded that it will not.

Review of these previous investigations does not show a relationship between design or operation of the overland flow process and its ability to remove algae. However, these investigations did show a relationship between the TSS concentration in the applied algae-laden wastewater and the ability of the overland flow process to meet secondary treatment limits.

This investigation established that the overland flow process preceded by a facultative lagoon did not meet the secondary treatment limits for TSS during algal bloom periods when the number of algae are two to three orders of magnitude greater than usual.

Both the number and species of plankton in the applied wastewater controlled the ability of the overland flow process to meet the secondary treatment limits for TSS.

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